Precision Accelerator Thrust (No υ's)

Chris Polly, Fermilab

DOE Laboratory Intensity Frontier Research Review

May 21, 2013

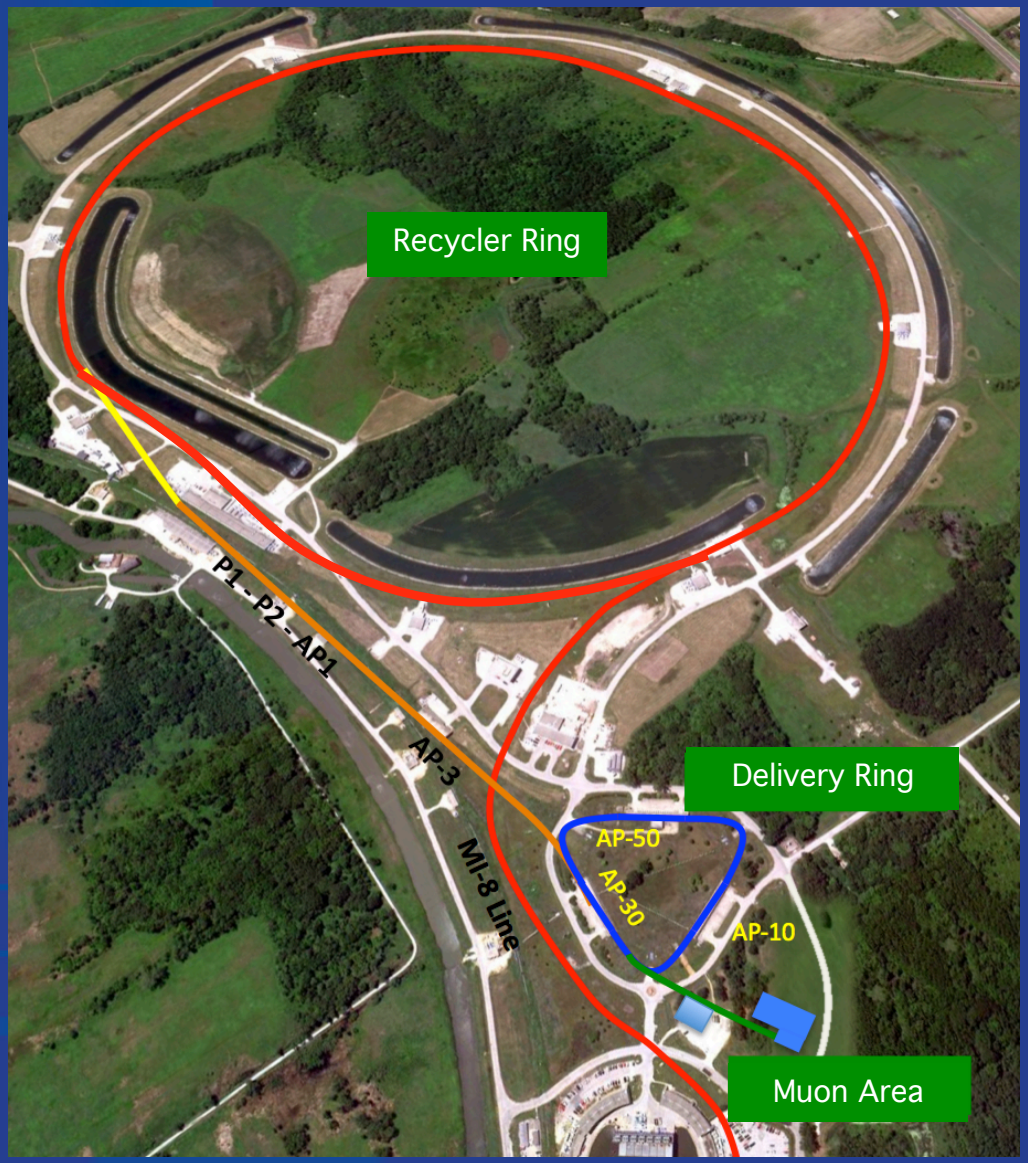
U.S. DEPARTMENT OF ENERGY

Fermilab

Recurring themes among FNAL scientists

- Innovation in developing proposals
- High-level project management tasked with delivering experiments
- Scientific leadership within the experiments
- Fostering science within the collaboration, the HEP community, and the public
- Warning: About 38 (KA22) scientists listed in this talk, can't possibly cover all contributions

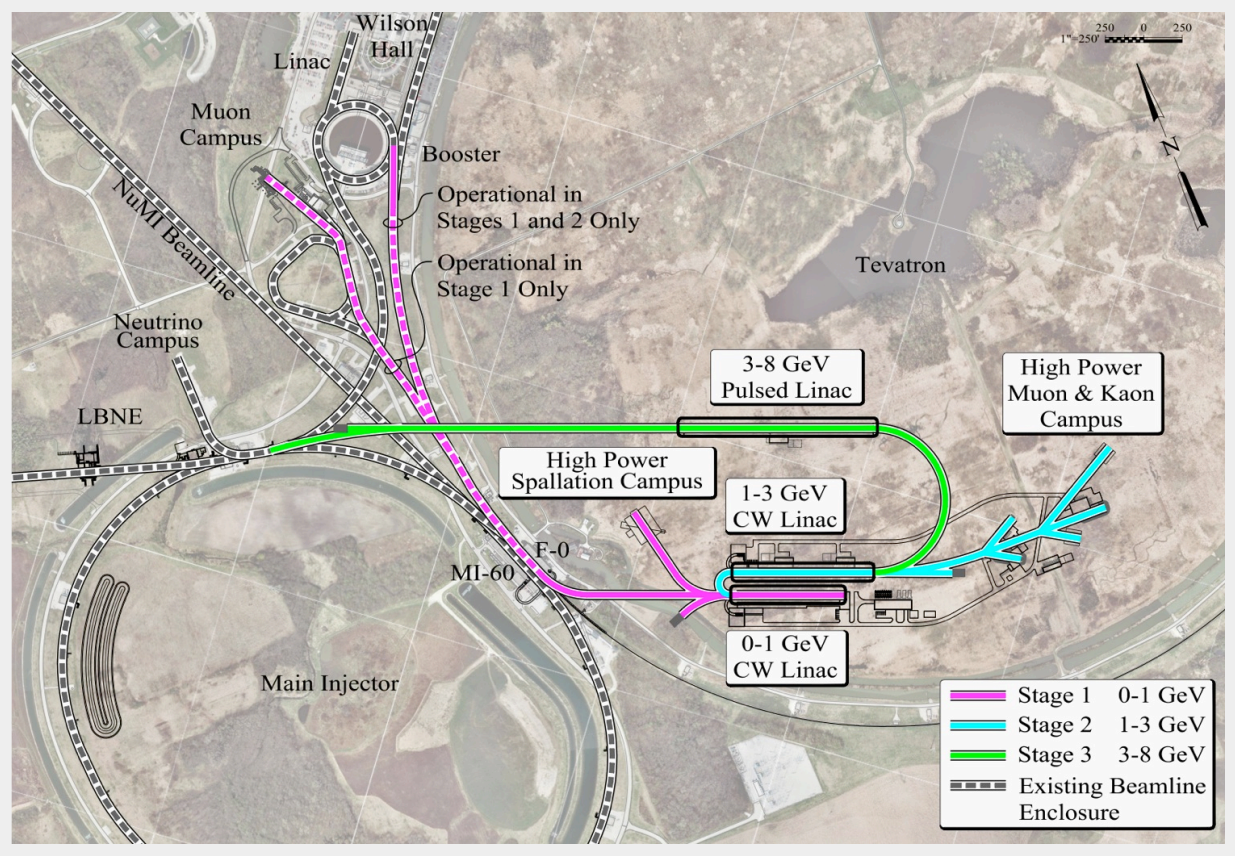
Plotting a course for the near-term…



Successful completion of Tevatron Run II opened unique possibilities for a future program with existing infrastructure

- Leverages a national asset
- Capable of providing world-class particle physics this decade
- Fermilab scientists absolutely central in developing a practical transformation from Run II to world-class fixed target program

…while keeping an eye towards the future



Project X design capable of producing most intense beams on the planet

Even at Stage 1:

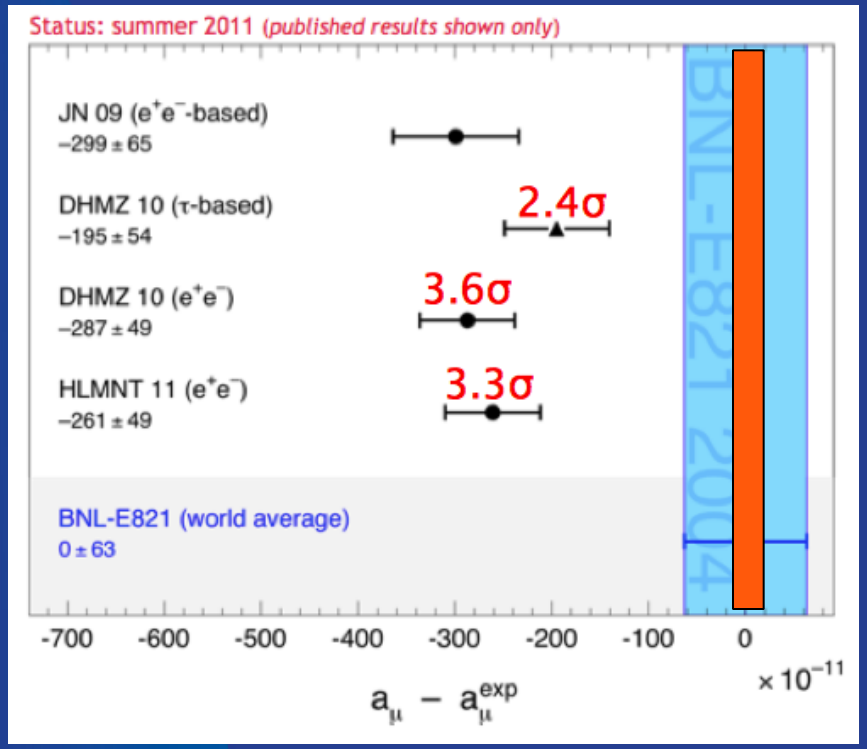
- 8 GeV Booster protons (20kW -> 40 kW)
-120 GeV MI protons (700kW -> 1200kW)
- 1 GeV Project X (900kW)

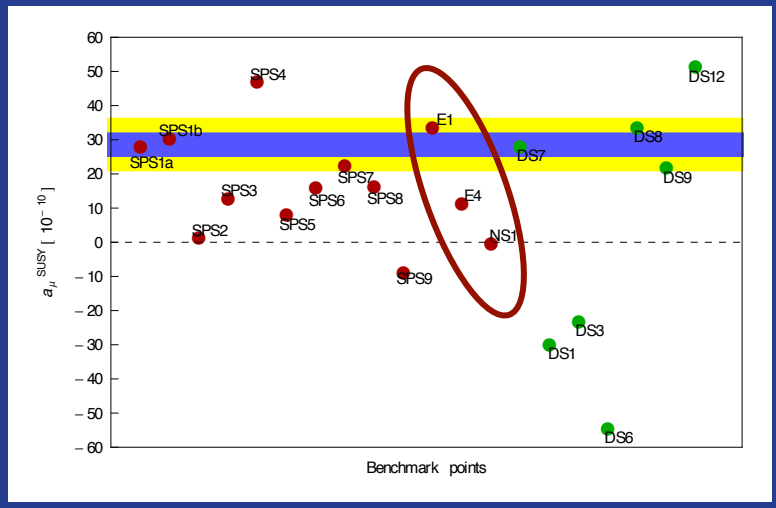
Fermilab scientists working on efforts to propose new physics programs

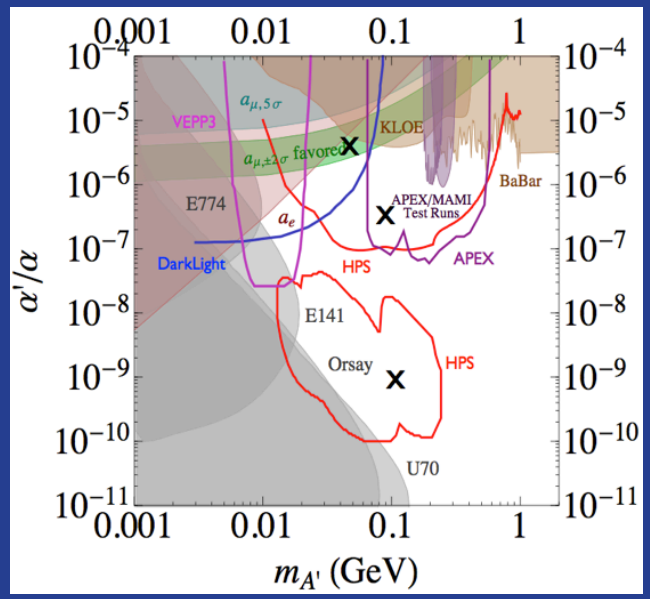
Outline for today

- Pushing Muon g-2 to the discovery threshold
- Probing 1000 TeV with Mu2e
- Development of a coherent muon program
- 1000 event golden mode in ORKA
- Evolution of the program through Project X

Muon g-2 Motivation: Harbinger of new physics







Unique probe of new physics

- Chirality-flipping, most LHC searches are not
- CP and flavor-conserving, unlike many other low energy observables
- Sensitive to sleptons and sign(μ) in SUSY, dark matter models

Could be why g-2 is the only precision observable hinting at new physics

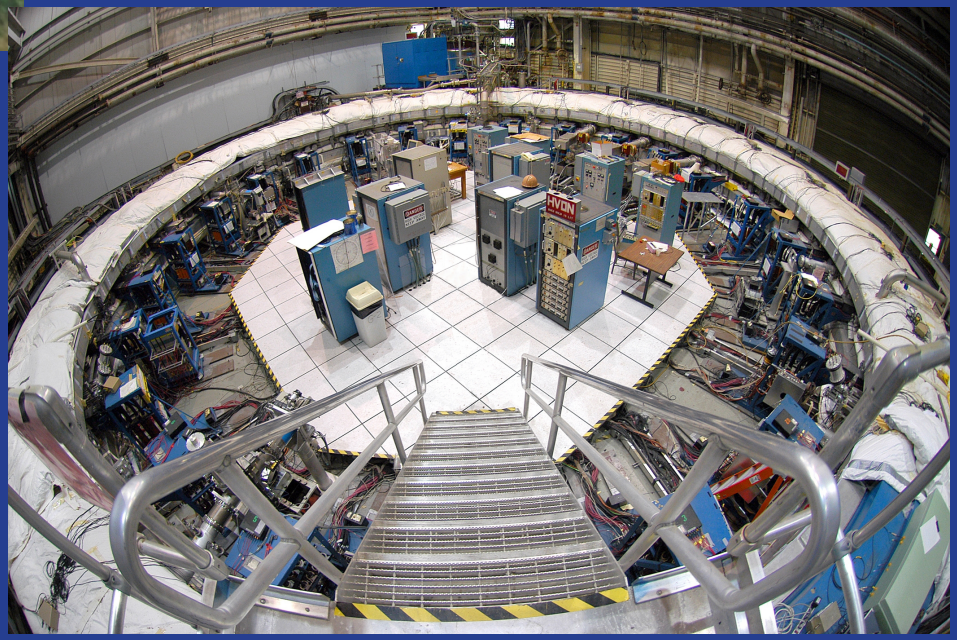
Muon g-2 Overview & FNAL Cast

B. CASEY	Detector L2, Tracker L3, Tracker R&D
M. CONVERY	Accelerator L2
T. GADFORT	Simulations and inflector
C. JOHNSTONE	External beamline
B. KIBURG (RA)	Storage ring modeling and installation
A. LYON	Head of computing & simulations
W. MERRITT	Deputy Project Manager
H. NGUYEN	Storage ring L2, Magnet R&D
C. POLLY	Project Manager
M. ROMINSKY (RA)	Testbeam and tracker R&D

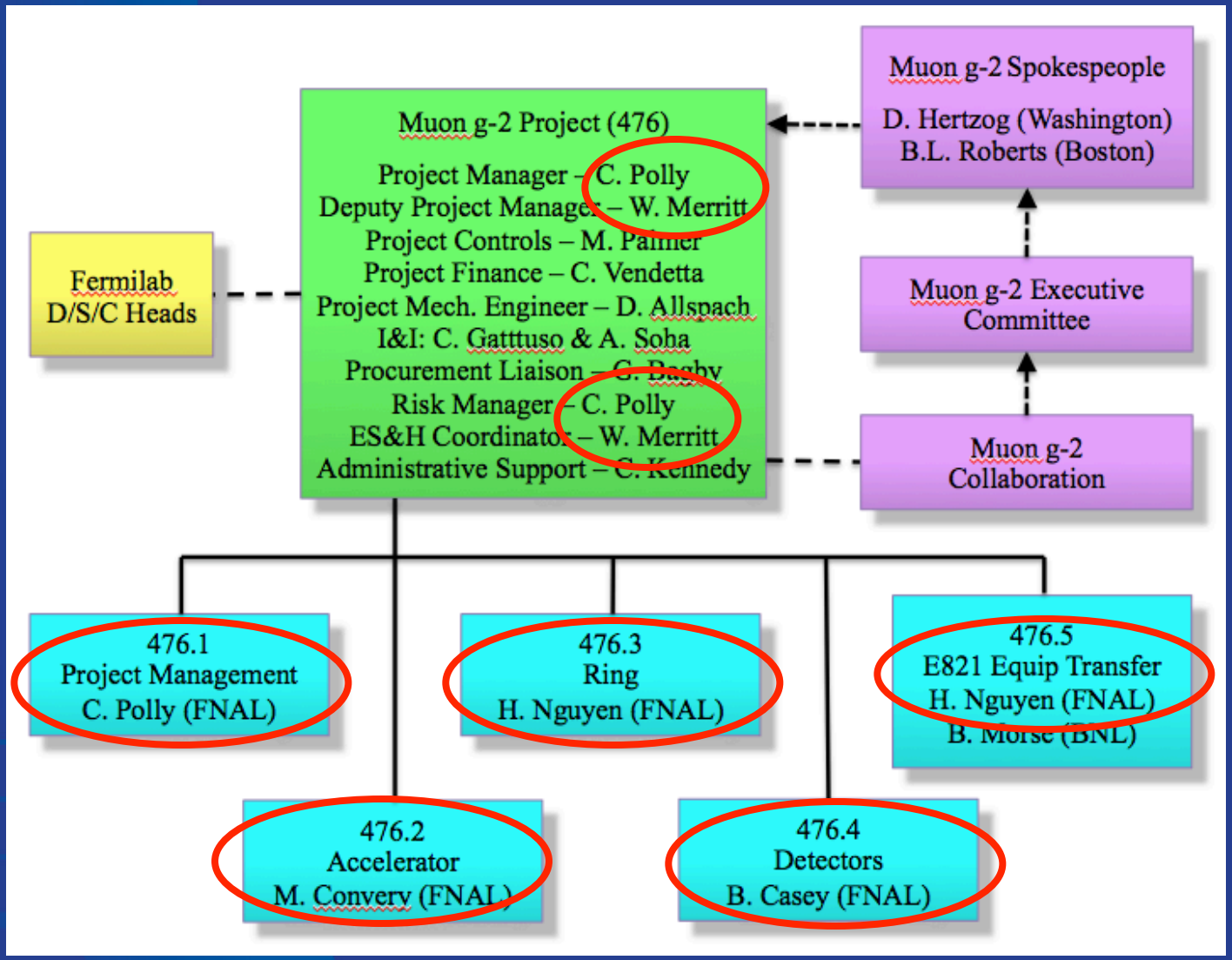
*No conveners/analysis coordinator types since experiment is in project phase

Can happen on a short timescale (2016 data)

- Transport storage ring and E821 equipment from BNL to Fermilab
- Convert anti-proton source into muon source
- Upgrade ring sub-systems and detector packages
- Run expt for x4 improvement in precision,
  > 5σ sensitivity to BNL discrepancy



Muon g-2 KA22 Scientists in Project (to L2)



Project received Mission Need in Sep 2012 (CD-0)

Finalizing Conceptual Design in summer (CD-1)

Technical and Final Design complete by mid-2014 (CD-2/3)

Construction through data taking starting in mid-2016

Project office will be VERY busy!

L3 Positions not shown
- 7 FNAL
- 1 BNL, 1 ANL
- 7 University

*Adam Lyon – Head of computing and simulations

Promoting g-2 Collaboration

Argonne (Slow Controls, NMR Trolley)
Boston University (Straw Electronics, Fast Rotation)
Brookhaven (Quads, Storage Ring, DAQ, Analysis)
Budker (Straws)
Cornell (New Kickers, WFDs, Simulations)
Dresden (Theory)
Fermilab (Ring, Accel, Traceback, Dynamics, Field)
Frascati (Calibration, SiPMs)
Illinois (Clock, Electronics)
James Madison (Muon Losses)
JINR, Dubna (Straws)
Kentucky (DAQ)
KEK
KVI (Magnetic Field)
Massachusetts (Magnetic Field)
Michigan (Magnetic Field)
Muons Inc. (Beam & Target Design)
NIU (Straws and Ring Transport)
Northwestern (Tracking, Theory)
Osaka (Calorimeter)
PNPI (Straws)
Regis (Fiber Harp Monitor, Analysis)
Rome (Calibration)
Shanghai (Calorimeter Crystals)
Virginia (SiPM Low Voltage)
Washington (Calorimeters, Dynamics, Field)
York College (Storage Ring Simulation)

Fermilab is a User facility, responsibility of project and FNAL scientists to recruit and enable

- Casey/Polly seminar tour to spread word of g-2 (Cornell, NIU, Northwestern)
- Lyon establishing global simulation & analysis framework in group computing environment, computing liaison to all
- Kiburg/Lyon hosted simulation workshops to train collaborators
- Casey/Polly served as spokespeople for test beam runs for universities to test detector/DAQ development
- Rominsky/Casey created straw test stand, engaging students and collaborators
- Nguyen/Polly established work parties at BNL for grad students/RAs to aid in disassembly

Working to establish a positive environment for collaborators feel welcome to come and be part of intellectual center

Examples…

Peter, ANL Associate Scientist

Brendan, UW Postdoc (now FNAL LF)

Leah, Northwestern postdoc

* All examples of young non-FNAL scientists gaining experience via work environments established by lab scientists

Volodya, BNL Associate Scientist

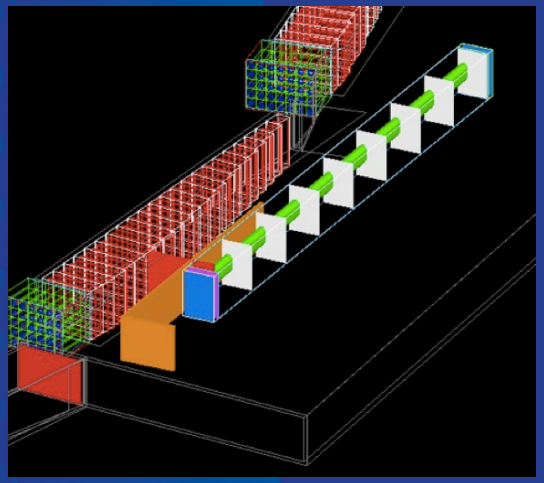
Robin, Cornell grad student

Nathan, UW grad student

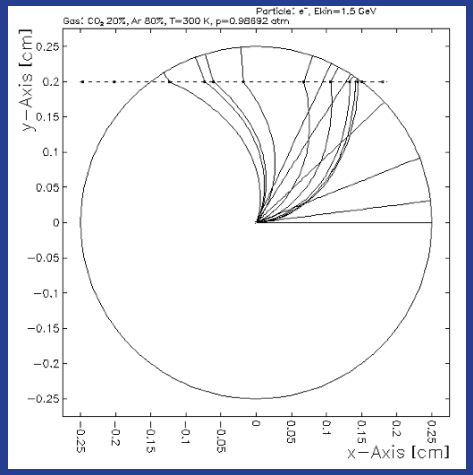
Students at Straw R&D

Muon g-2 Future Scientific Focus I

- Disassembly, transport, and reestablishing the experiment at Fermilab (Nguyen, Polly)
- Development of simulation framework for injection (Gadfort, Kiburg, Lyon)
- Development of trackers based on in vacuo straw technology (Casey, Rominsky)

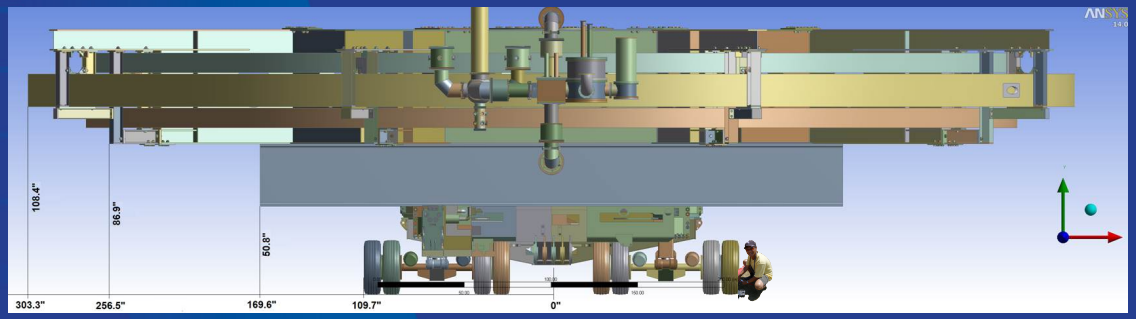


Gadfort leading G4 sim. effort for inflector/kicker/quad design

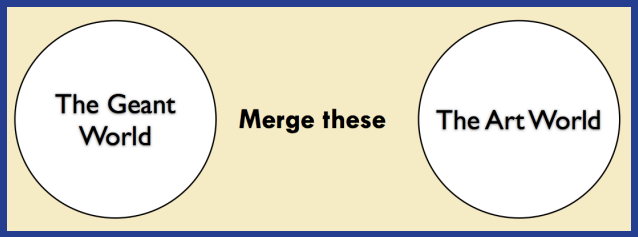


Rominsky Garfield simulation of straw repsonse

Polly Coordinating building specs to meet experimental needs



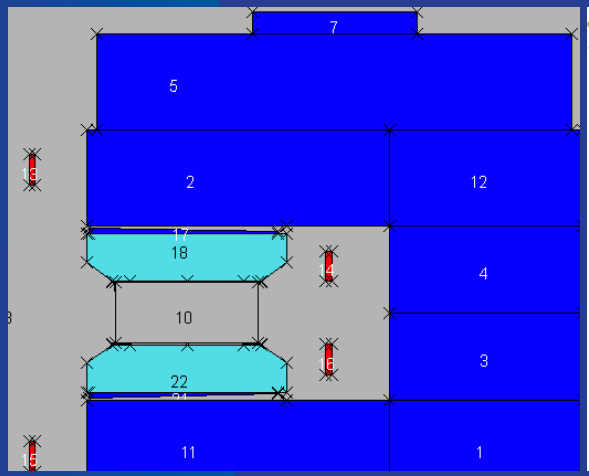
Nguyen/Polly coordinating of safe transport of E821 equipment, 2013 high priority

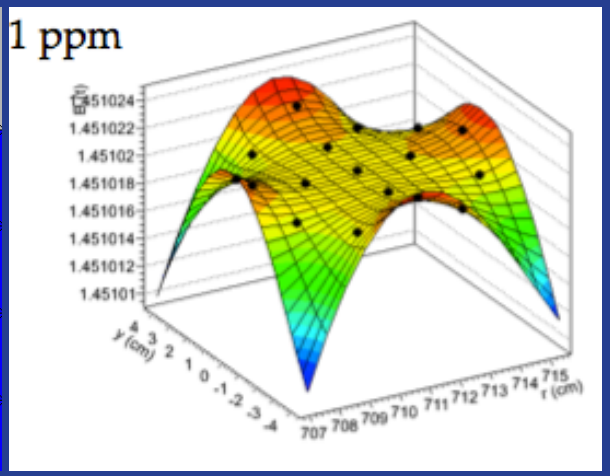


Lyon coordinating merge of G4 with ART

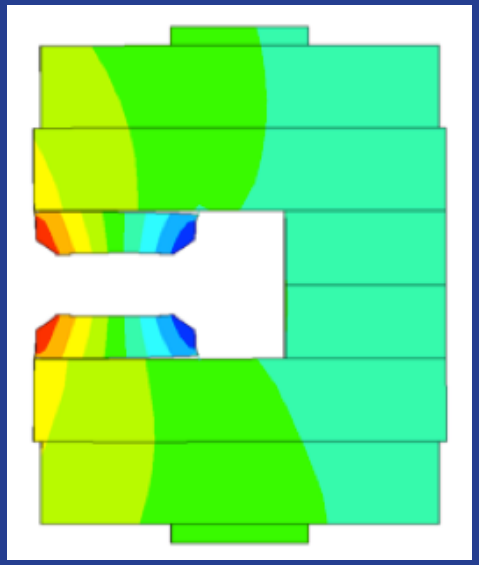
Muon g-2 Future Scientific Focus II

- Shimming the storage ring to unprecedented field uniformity (Kiburg, Nguyen)
- Field measurement R&D (Kiburg, Nguyen)



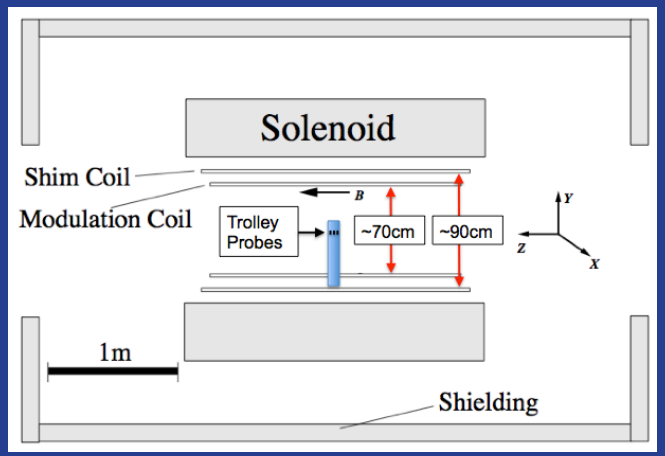


Kiburg leading OPERA 2D modeling of field shimming kit, analysis of multipoles



Nguyen ANSYS model of thermal distortions

Nguyen establishing high-field, high-uniformity, large bore test magnet

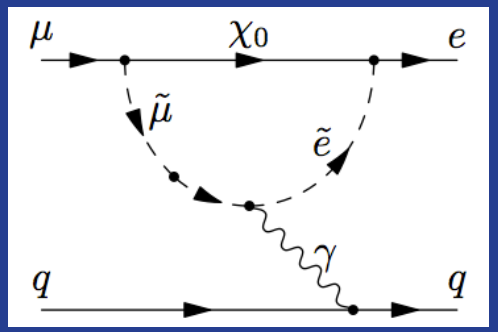


* Many more examples of code development and studies in the ART G4 framework…

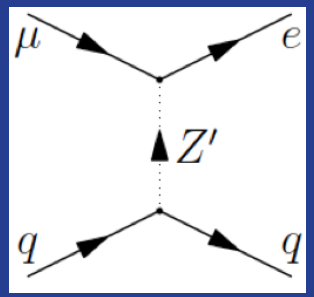
Mu2e Motivation: Probing $\mathcal{O}$(10000 TeV)

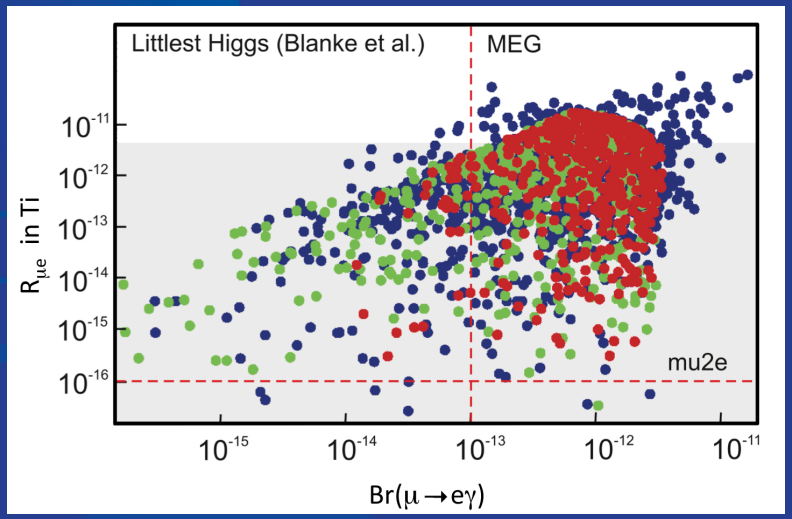
Mu2e one of very few ways to probe 1000 TeV scale

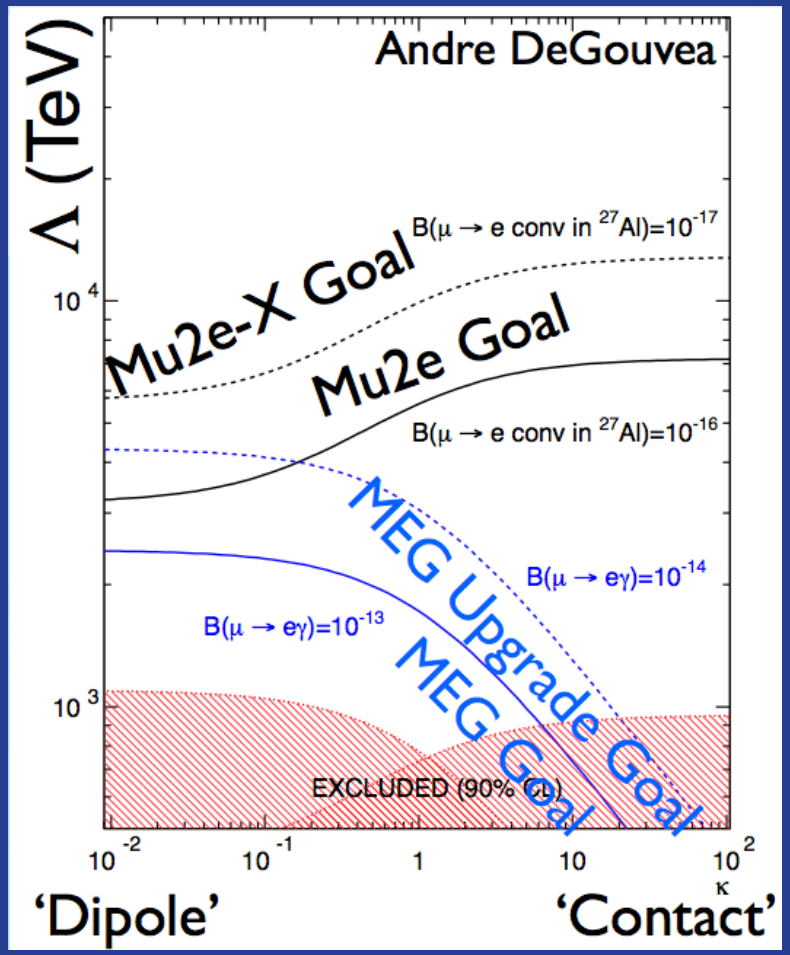
Dipole terms
- SUSY
- Heavy Neutrinos
- Higgs Doublet
- Also probed by MEG



Contact terms
- Leptoquarks
- Compositeness
- Anomalous heavy couplings

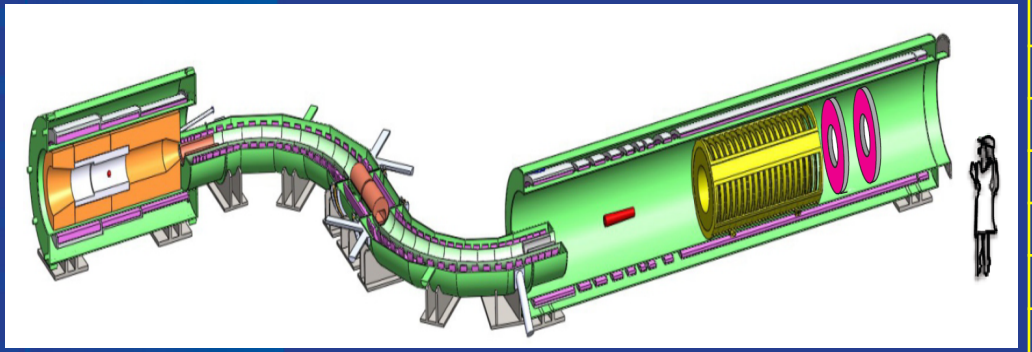






$$L = \frac{m_\mu}{(\kappa+1)\Lambda^2}\bar{\mu}R\sigma_{\mu\nu}e_L F_{\mu\nu} + \frac{\kappa}{(\kappa+1)\Lambda^2}\bar{\mu}_L\gamma_\mu e_L \sum_{q=u,d}\bar{q}_L\gamma^\mu q_L$$

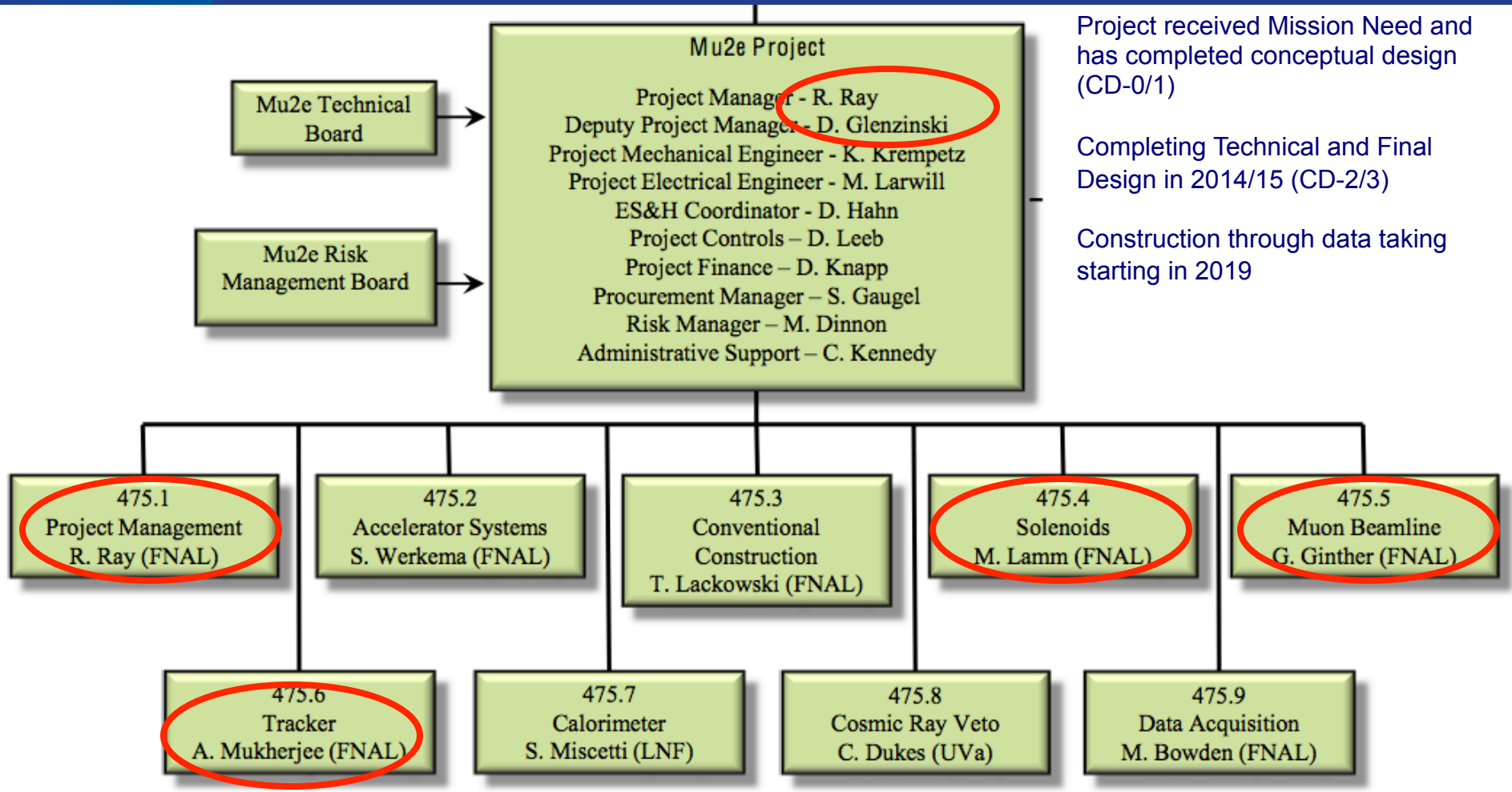
Mu2e Overview & FNAL Cast



- Construct extensive solenoid system
- Convert anti-proton source for slow spill proton extraction to target in PS
- Produce, install, and read out straw tracker and calorimeter
- Control backgrounds and extend sensitivity to mu-e conversion by 4 orders of magnitude!

G. AMBROSIO	Transport solenoid
R. BERNSTEIN	Co-Spokesperson
M. BUEHLER	Magnet meas. and simulation
R. COLEMAN	Target Station L3, magnet R&D
S. FEHER	Detector Solenoid L3
A. GAPONENKO (WF)	Beam extinction monitor
G. GINTHER	Muon Beamline L2
D. GLENZINSKI	Deputy Project Manager, veto R&D
C. JOHNSTONE	Extinction beam L3, beamline R&D
P. KASPER	Extinction monitor design
K. KNOEPFEL (RA)	Backgrounds, Project X upgrades
R. KUTSCHKE	Head of software and simulations
M. LAMM	Solenoids L2, solenoid R&D
M. LOPES	Design of trans/detector solenoids
S. MOED SHER	Extinction monitoring and analysis
A. MUKHERJEE	Tracker L2, Tracker R&D
G. PIACENTINO	Tracker development
A. PLA-DALMAU	Scintillator development
G. RAKHNO	Extinction beamline optimization
R. RAY	Project Manager, Detector R&D
V. RUSU	Tracker infrastructure L3
S. STRIGANOV	Anti-proton background
M. TARTAGLIA	Magnetic field mapping L3
G. TASSIELLI	Tracking algorithms
R. WAGNER	Tracking deputy leader

Mu2e KA22 Scientists in Project (to L2)



Project received Mission Need and has completed conceptual design (CD-0/1)

Completing Technical and Final Design in 2014/15 (CD-2/3)

Construction through data taking starting in 2019

*Rob Kutschke – Head of computing and simulations

Promoting Mu2e Collaboration

Boston (magnet field specifications, stopping target monitor, spectrometer calibration, simulations)
BNL (cathode strip chambers)
LBNL and UCBerkeley (tracker asic, pattern recognition and track fitting software, simulations)
UC Irvine (simulations)
Caltech (calo crystal R&D/calibration, DAQ, simulations)
CUNY (vacuum chamber for tracker R&D)
JINR Dubna (calorimeter crystal R&D, cosmic veto R&D)
Duke (tracker straw assembly and R&D)
INFN Frascati (calorimeter crystals, calo electronics, calo power supplies, calo R&D, simulations)
INFN Genova (TS coils R&D, superconductor QC)
U.Houston (tracker readout controller)
U.Illinois (calo electronics)
INFN Lecce (tracker support structure, simulations)
Marconi (simulations)
NIU (muon beam stop, simulations)
INR Moscow (simulations)
INFN Pisa (simulations)
Rice (tracker straw assembly, simulations)
INFN Trieste/Udine (calo photosensors, cosmic veto)
U.Virginia (cosmic veto design and construction)
U.Washington (testbeams)

Fermilab is a User facility, responsibility of project and FNAL scientists to recruit and enable participation

- Bernstein as co-spokesperson spends time working to keep community informed and engaged in Mu2e

- Kutschke implemented ART framework for Mu2e collaboration

- Glenzinski development of cosmic ray veto test stand at FNAL

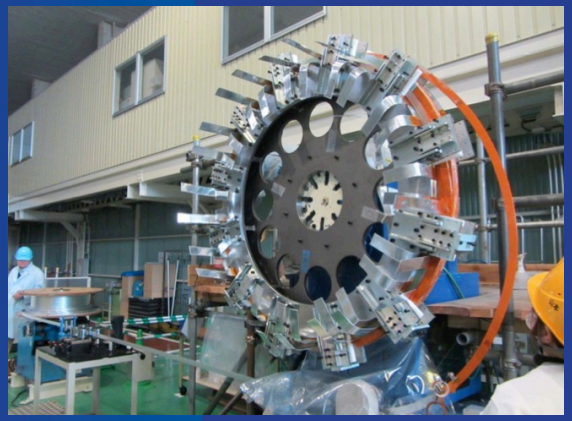
Unprecedented leap in sensitivity…task force leaders that organize various key efforts

- Gaponenko global backgrounds and sensistivity (previously led by Glenzinski/ Tschirhart)

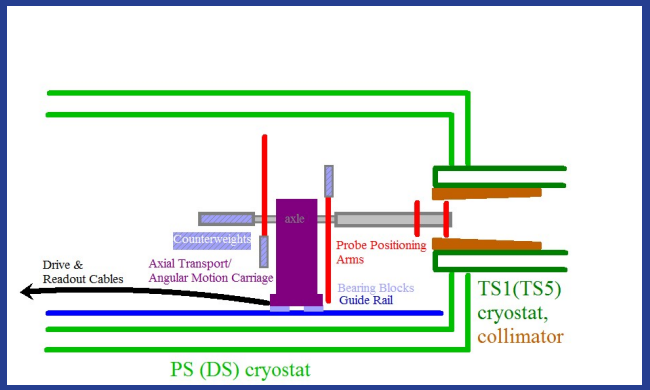
- Coleman neutron task force

Mu2e Future Scientific Focus I

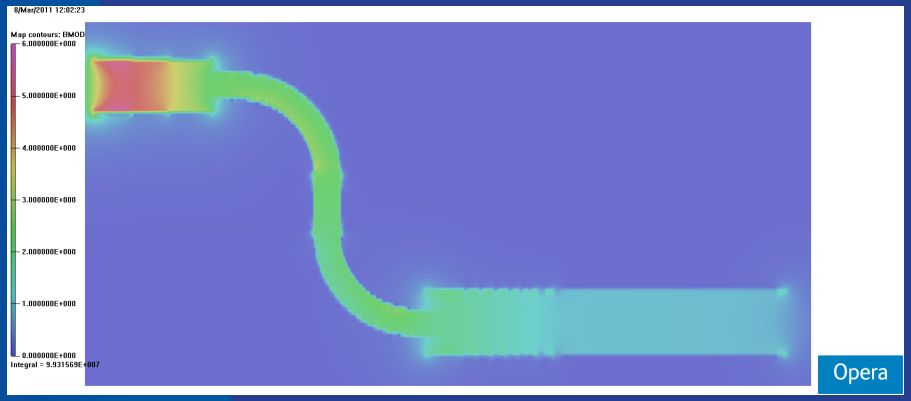
- Leading R&D for solenoid development (Ambrosio, Feher, Lamm, Lopes)
- Magnetic field prediction, mapping, and analysis (Buehler, Lopes, Tartaglia)



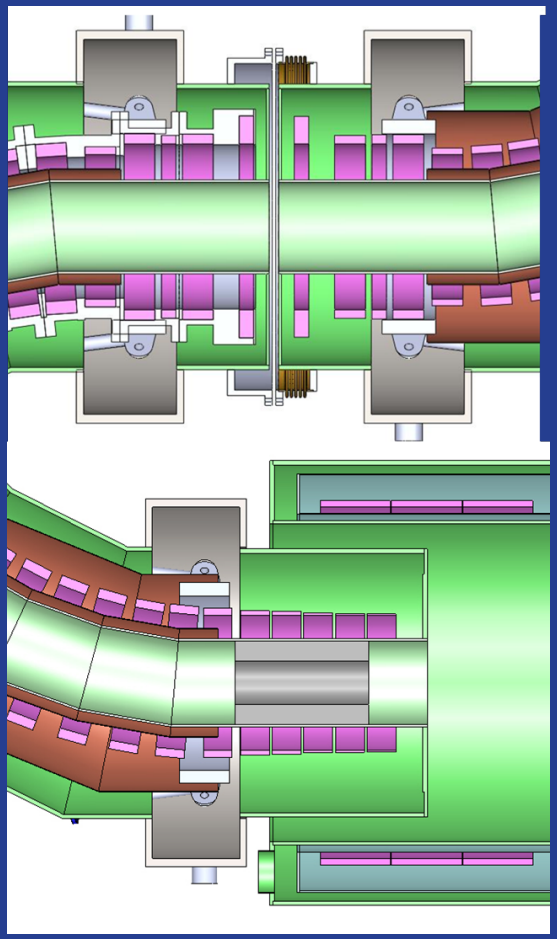
Lamm testing coil from Toshiba at FNAL



Tartaglia design of field mapping apparatus



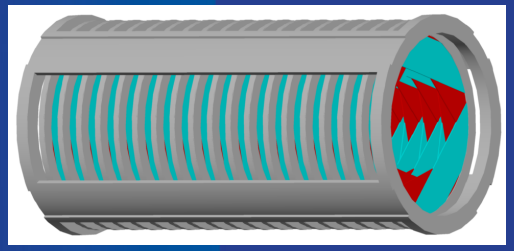
Lopes mapping solenoid fields in Opera



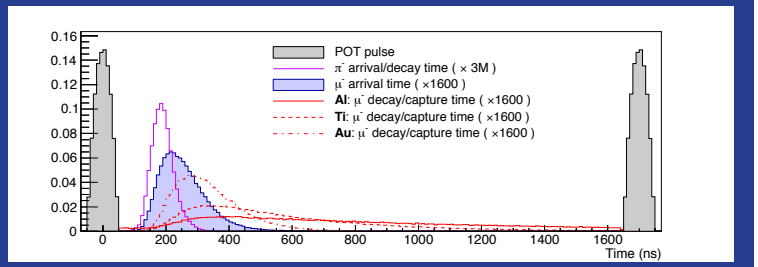
Ambrosio and team work on solenoid interface

Mu2e Future Scientific Focus II

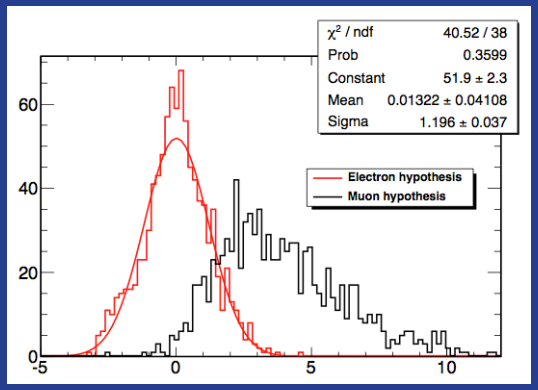
- Tracker R&D and algorithms (Mukherjee, Piacentino, Rusu, Tassielli, Wagner)
- Cosmic ray veto R&D and simulation (Glenzinski, Pla-Dalmau)
- Simulations, backgrounds, and DAQ (Bernstein, Gaponenko, Glenzinski, Knoepfel)



Mukherjee\Wagner designing and testing of tracker components

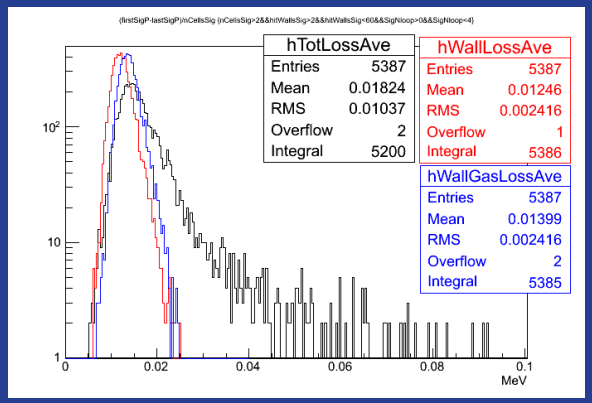


Knoepfel target composition



Rusu simulating tracker PID

Glenzinski test of CRV neutron response

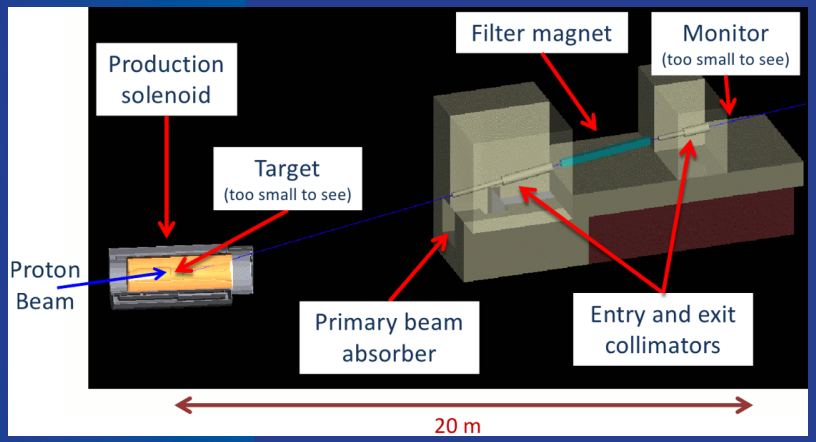


Tassielli simulating energy loss in straws

Pla-Dalmau scintillator extrusions for cosmic ray veto

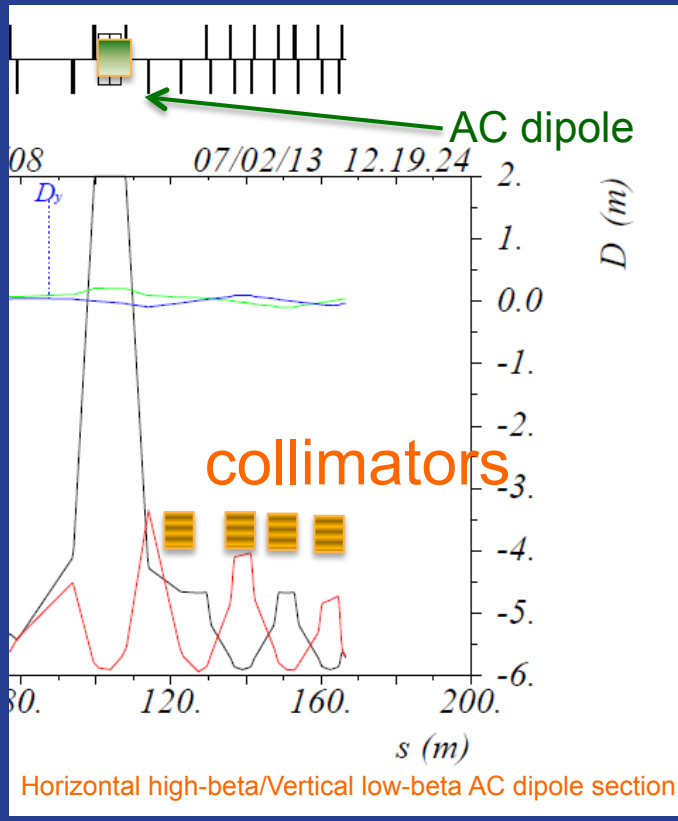
Mu2e Future Scientific Focus III

- Design and operation of muon beam line with high extinction (Ginther, Johnstone, Rakhno)
- Developing extinction monitor and analysis (Gaponenko, Kasper, Moed Sher)

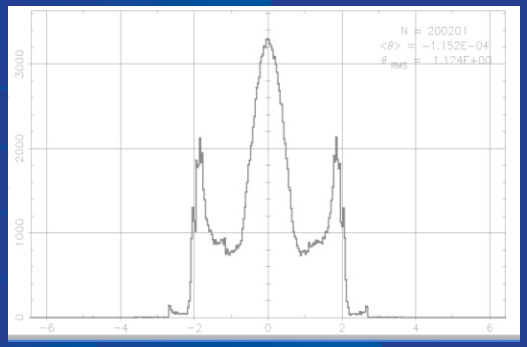


Gaponenko, Kasper designing and simulating extinction monitor

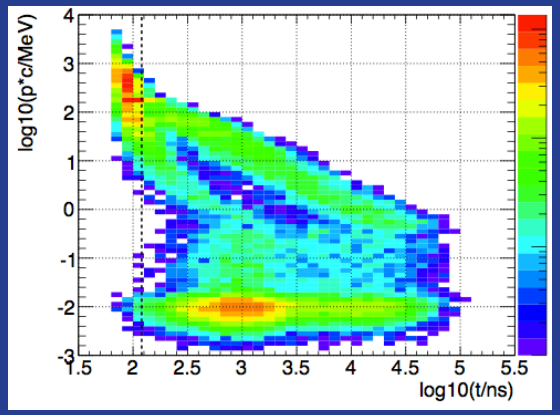
Apologies to the many scientific contributions not explicitly mentioned



Horizontal high-beta/Vertical low-beta AC dipole section

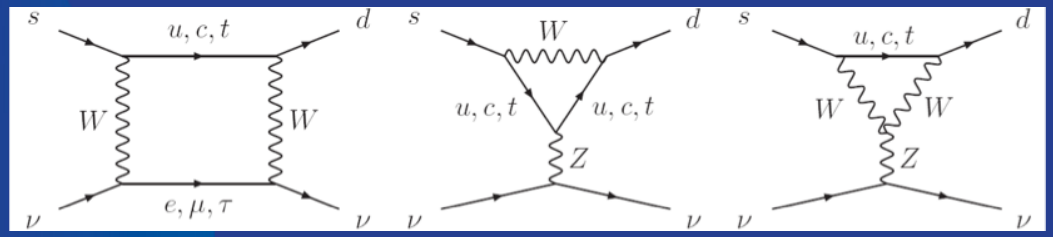


Moed Sher sources and rates for out-of-time protons



Gaponenko simulation of neutron backgrounds

Johnstone collimation downstream of AC dipole to achieve extinction



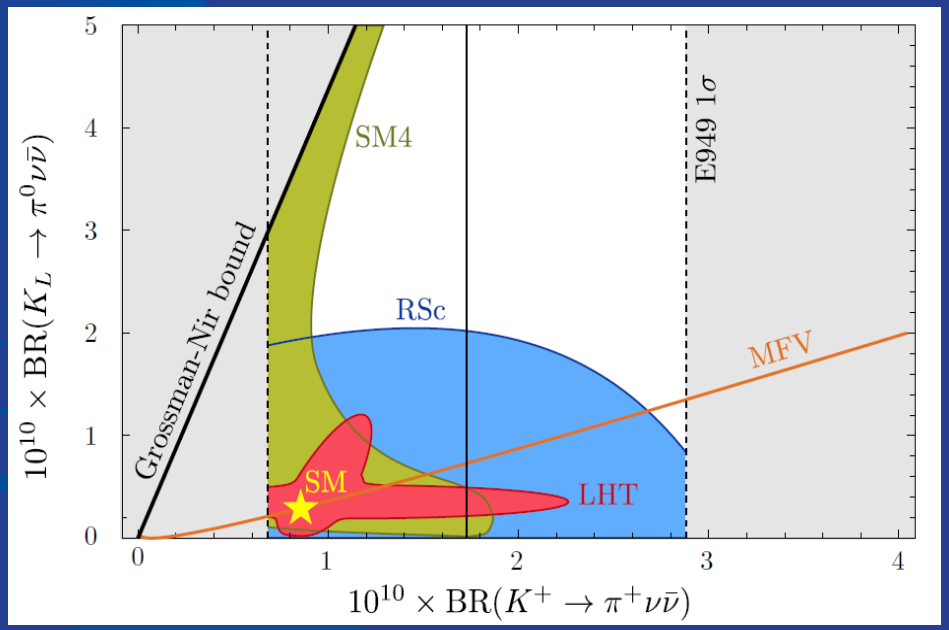
ORKA Motivation: 1000 event reach into the golden K^+ channel

$K^+ \rightarrow \pi^+ \nu \bar{\nu}$ is one a few SM FCNC that can be precisely calculated BR = (7.8 ± 0.8) x 10^{-11}

Single loop effective operator, dominated by top, excellent lattice calculations with major involvement from FNAL theory department

Special status relative to other future proposals

- 4th generation experiment
- advanced conceptual design
- Positive PAC response and Stage 1 Approval from FNAL director

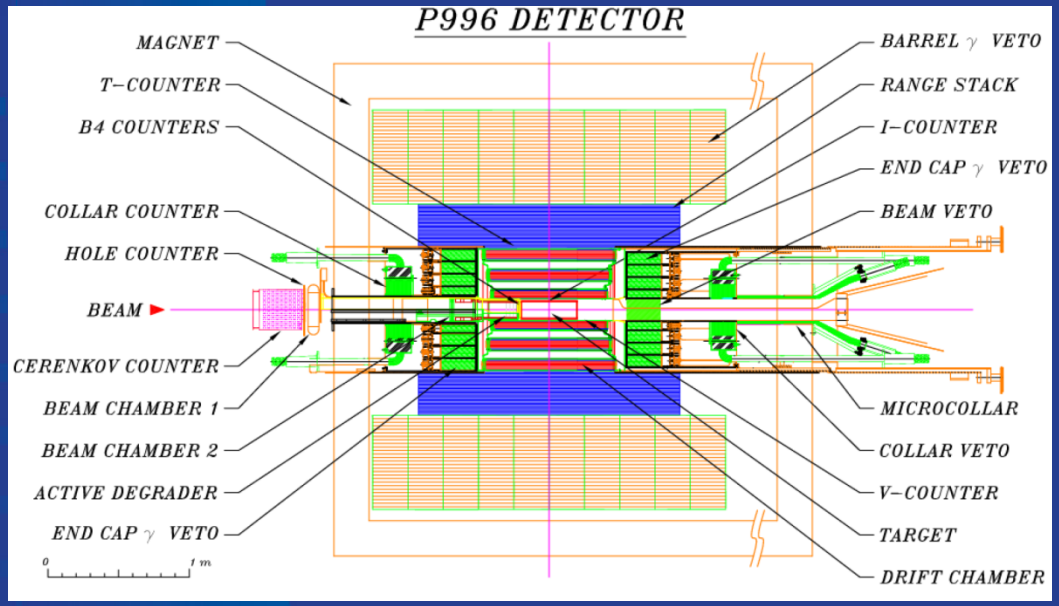


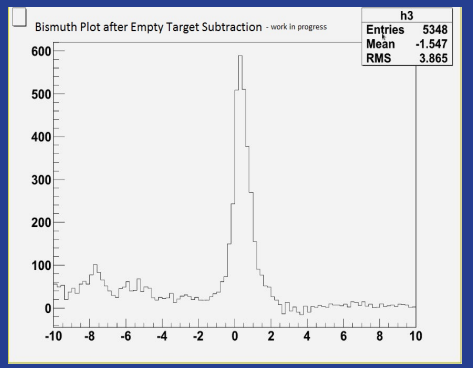
Sensitive to new physics entering via loops

- 3 models shown at right with current limits from E949 and GN bound

ORKA R&D Overview & FNAL Cast

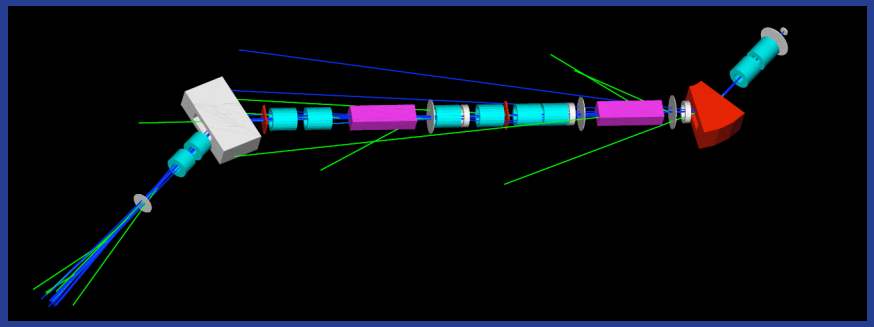
B. CASEY	Analysis of MIPP data
D. CHRISTIAN	Siting at CDF, DAQ
A. GAPONENKO	Simulations
D. JENSEN	Dogleg beamline
J. LEWIS	CDF siting and costing
R. TSCHIRHART	Co-Spokesperson
H. WHITE	Primary beam design





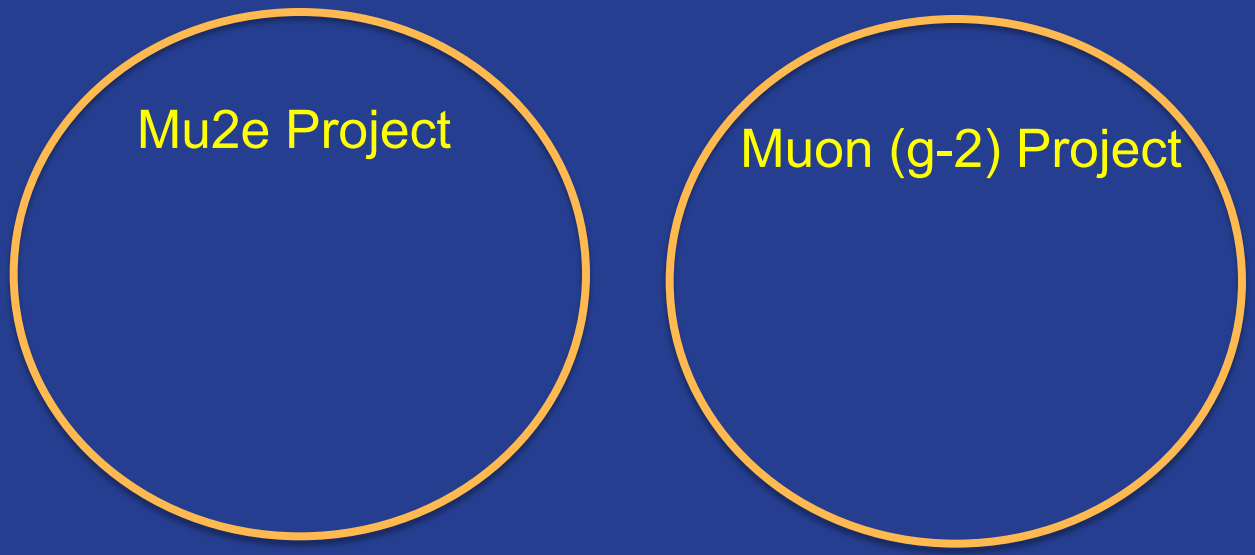
Casey analysis of MIPP data

- Propose to place experiment in CDF hall
- Lab keeping the option to mount ORKA (or other experiment) in the hall
- Construct upgraded version of E949 detector reusing CDF solenoid
- Deliver 95 GeV beam from Main Injector
- Technically-driven schedule capable of data in 2017



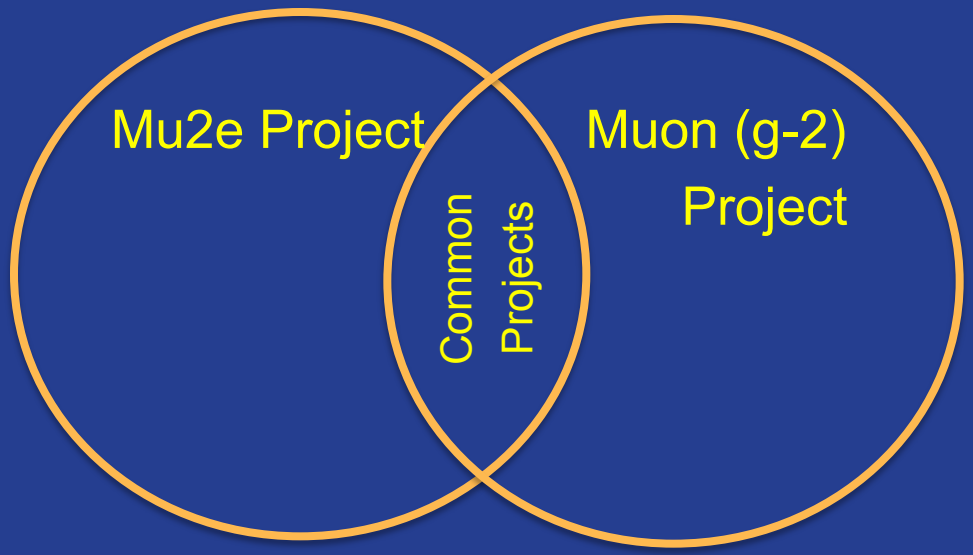
Jensen G4 simulation of dogleg

Development of a coherent Muon Program



- Two years ago Mu2e and Muon (g-2) were two separate projects… potential synergies and conflicts had been identified, but not resolved

Development of a coherent Muon Program



How Mu2e and Muon g-2 look today…

- Areas of conflict identified and resolved
- Areas of synergy identified and optimized
- Muon program developed to meet the scientific requirements while minimizing the total cost of the program

Synergistic plan emerges for muon program

Optimized plan presented to DOE in Jan 2012 by Glenzinski, Polly, Ray, and Jerry Annala (new head of muon dept)

Recycler RF AIP:
Adds RF capability to Recycler meeting g-2/Mu2e specifications

Delivery Ring AIP:
Modify Delivery Ring to deliver custom beams to the muon experiments

Beam Transport AIP:
New connection from Recycler to Delivery Ring, improve apertures

MC-1 Building GPP:
Houses cryo plant, power supplies for beams, g-2

Cryo Plant AIP:
Cryogenics to both experimental halls

Beamline Enclosure GPP:
New tunnel to Muon Campus

Infrastructure Upgrades:
Cooling for A0 compressors, MI-52 building extension, added feeder if needed

Exceptional scientists, but really much more…

Fermilab scientists play a vital role as conduits of information and coordination to develop new proposals, make the tires meet the pavement, and implement the OHEP mission

The plan for the Muon program could never have arisen were it not for help from many corners of the laboratory and collaborations

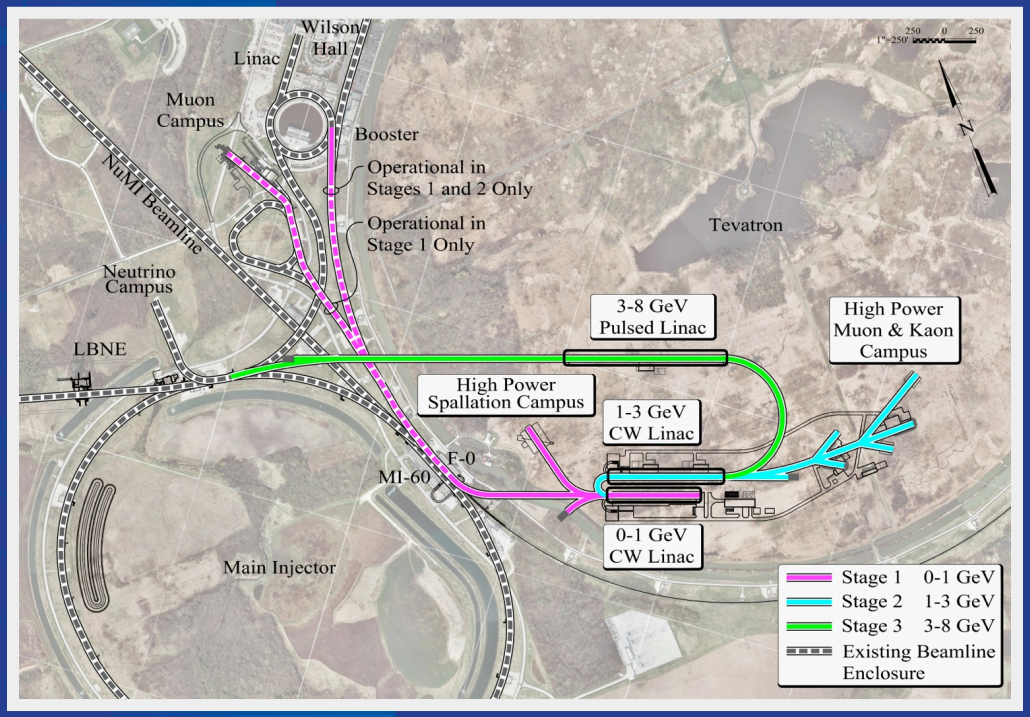
Can see this same thing in the neutrino program

Picture of high-rise backyard in a few years

The success of this program will hinge on the continued coordination effort from many of the scientists discussed today...interfaces critical

That coordination will continue into the era of new, even more intense beams

- Project X Plan continues to evolve based on input from scientists
- Paper-clip' design driven by maximizing physics potential



Day 1 possibilities with Stage 1

- Feed Booster to double beam to muon program (Muon g-2 or next expt in hall)
- Similarly increase beam power in MI to support neutrino or kaon program
- Direct 1 GeV beam with ideal beam structure directly to upgraded Mu2e for > 10x statistics
- 900 kW at 1 GeV

Build out 3 GeV upgrade with no interference to running program

- Feed 3 GeV beam to kaon experiment upgrade in CDF hall (not shown)
- New 3 GeV campus

Conclusions

Fermilab physicists are playing vital roles in developing a compelling, viable precision physics program with continuous physics output

- Starts with Muon g-2 data in 2016 and Mu2e in 2019
- Many avenues for future efforts like ORKA or other muon experiments
- Natural evolution into stage 1 Project X era

Strong and balanced portfolio of project management, scientific achievement, and collaboration leadership

Working very hard with our colleagues from universities and other laboratories to establish a bright future at the Intensity Frontier